PATENT

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TEMPERATURE SENSITIVE PATTERNED MEDIA TRANSDUCERS

FIELD OF THE INVENTION

This invention concerns temperature sensitive playback transducers for data storage systems in which data is recorded in patterned media.

BACKGROUND OF THE INVENTION

To meet the insatiable demand for inexpensive and inexhaustible data storage, the long and steady march of progress in the field of data recording and electronic playback has relied on many technical approaches. No approach has outperformed the versatility and extremely high storage densities of magnetic recording, in which a signal is recorded by selectively varying the magnetic moments of physical regions of media such as flexible tapes or rigid (typically rotating) disks. Another broad class of approaches relies on variations in the physical shape of the surface of the media. Such features are not detected directly, but rather are used to cause corresponding variations in characteristics such as reflectivity, coercivity, and the like that may be detected accordingly (*e.g.*, an optical detection system, in the case of variations in reflectivity).

SUMMARY OF THE INVENTION

The invention involves non-magnetic transducers for patterned media systems. More specifically, such transducers comprise a temperature sensitive resistor and a bias current path including the temperature sensitive resistor. The temperature sensitive resistor may comprise a thermistor, for example, a thermistor comprising a material selected from the group consisting essentially of Co_2O_3, MN_2O_3, NiO, and boron-doped

diamond-like carbon. Other embodiments of the temperature sensitive resistor comprise a resistance temperature detector, for example a resistance temperature detector comprising a material selected from the group consisting essentially of nickel and platinum. Other embodiments of the transducer are thin film structures. The transducer and the leads may be of the same material but this is not required. The transducer may be generally V-shaped but this is not required. The transducer may further comprise a heating element in close proximity to the temperature sensitive resistor. It may also further comprise a coating layer. A transducer of the invention defines a film plane, and the bias current path may lie parallel or perpendicular to the film plane.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings show a particular embodiment of the invention as an example, and do not limit the scope of the invention.

Figure 1 is schematic view of a patterned media system.

Figure 2 is a schematic view of the transducer of Figure 1.

Figures 3-7 are schematic views of other embodiments of the invention.

DETAILED DESCRIPTION

In general terms, the invention includes various embodiments of data playback transducers that utilize temperature sensitive resistors to create signals representative of patterns of physical features present in the surfaces of patterned media. Thus, the recorded data (typically in a known format or pattern) is represented in some manner in variations in the physical features on the patterned medium. A transducer of the invention "senses" (or otherwise reacts to) these variations to produce a signal that represents the data recorded on the medium. The transducer is connected in any convenient manner (usually an electrical or electronic connection) to appropriate circuitry that can process the

transducer signal as required. These connections and circuitry are not part of the invention.

Figure 1 is a general schematic diagram of a data storage system **100**. In general terms, the invention includes various embodiments of a non-magnetic playback transducer **200** that utilizes temperature sensitive resistors to create a signal **300** representative of topographical features **400** present in the surface **510** of a patterned medium **500**. Thus, the data **600** has been recorded, or represented in a known format or pattern, in variations in the physical features **400** on the patterned medium **500**. Transducer **200** senses physical features **400** and produces a signal **300** that represents the data **600** recorded on the patterned medium **500**. The transducer **200** is connected in any convenient manner (usually an electrical or electronic connection) to appropriate circuitry **700** that can process the transducer signal **300** as required.

Figure 2 shows top, front, and side schematic views of one embodiment of the invention. Transducer **200** comprises a temperature sensitive resistor (TSR) **210**, *i.e.*, an element that varies in electrical resistivity as a function of its temperature. One broad class of TSR included in the scope of this embodiment is known as a thermistor, and another broad class of TSR included in the scope of this embodiment is known as a resistance temperature detector (RTD). Thermisters and RTDs utilize the temperature dependence of resistivity of semiconductors and metals, respectively.

In either case, a bias current is placed through the device (as indicated by the dashed line and arrows) on leads **220** and **221**. The change in electrical potential (voltage) through the TSR due to the resistivity of the material is measured by connecting leads **220**, **221** to appropriate circuitry **700** (see Figure 1). All other factors being equal (or appropriately taken into account), measured changes in the resistivity are due to actual changes in the temperature experienced by the TSR, such as those changes created by exposing it to the variations in features **400** of patterned medium **500** (see Figure 1).

Any materials that produce the required temperature varying resistivity are suitable. Possible thermistor materials include Co_2O_3, MN_2O_3, and NiO. Another possible material is a boron-doped diamond-like carbon (DLC) material, or B-DLC, which is suitable in some applications because of its very high sensitivity, high thermal conductivity, and low specific heat; these properties are associated with faster response times than other materials. Possible RTD materials include nickel and platinum.

Figure 3 is a schematic representation of a specific embodiment of a RTD transducer **200**. In general terms, this embodiment can be envisioned as a thin film structure in which the resistor **210** and the current carrying leads **220, 221** are the same material. A single-step process, such as a single deposition using conventional deposition equipment, is one possible (but not required) manufacturing technique permitted by use of a single material. In the context of this process, transducer **200** defines a so-called "film plane" that is parallel to the front view of the device. The design of Figure 3 also is relatively simple in shape and therefore involves fewer and simpler lithographic steps in its manufacturing process, even if more than a single step is involved.

In general terms, transducer **200** comprises an element portion **210** that presents a recording surface **230** that is sometimes called a "gap" or "detection region" by analogy to the space between opposite polarity magnetic poles used in conventional magnetic data recording. However, in the transducers of this invention, no open space is required. The transducer **200** is mounted in a conventional manner on a slider or other platform (which is not shown for clarity). Transducer **200** is mounted so that recording surface **230** is generally parallel to the surface **510** of the patterned medium **500**. As indicated by dashed lines, the bias current flows to and from the recording surface **230** through each of a pair of leads **220**, **221** that are arranged to direct the current flow generally perpendicular to the surface **510**.

The shape of transducer **200** is schematic only and should not be considered a limitation on the scope of the invention. Nonetheless, it can be said that in the embodiment shown, transducer **200** is generally V-shaped in overall appearance, with the playback element **210** residing between the arms **220**, **221** that form the leads of transducer **200**. The size and shape of playback element **210** defines detection region **230**. A detection region **230** of approximately 0.3 micrometer would be suitable for a transducer **200** manufactured from nickel, but this is only an example and not a limitation on the scope of the invention.

In the case of a thermistor-based transducer **200**, the resistivity of the material typically chosen would typically be many orders of magnitude greater than that of RTD materials. Therefore, as illustrated in Figure 4, it would be possible to pass the current through transducer **200** perpendicular to the thin film plane, as indicated by the dashed line. This produces a transducer **200** that is thicker in the perpendicular direction, but otherwise transducer **200** is somewhat V-shaped in the parallel direction, similar to the embodiment of Figure 3. As before, transducer **200** generally comprises an element portion **220** that presents a detection region **230** parallel to the surface **510** of patterned medium **500**. Current flows to and from the detection region through each of a pair of leads **220**, **221** that are arranged to present the current flow direction generally perpendicular to the recording surface. As before, transducer **200** is generally V-shaped in overall appearance, with the playback element portion **210** residing between the arms of the transducer **200** and defining the detection region **230**.

Again a detection region of approximately 0.3 micrometer would be suitable for a transducer **200** manufactured from a material such as B-DLC, but this is only an example and not a limitation on the scope of the invention. To achieve this value, it is possible to use a B-DLC element **210** that is doped in a conventional manner to a resistivity of 10^3 ohm-cm, has a thickness of approximately 10 nanometers, and lateral (detection region) dimensions of 0.3 micrometer by 2 micrometers. This would produce an element

210 having a resistance of approximately 170 x 10^3 ohm, a value that would significantly limit current flow through transducer **200**, even for bias potentials on the order of 10 volts. However, B-DLC has been shown to be suitable for TCRs in excess of 100% per Celsius degree, which may provide a signal sufficient to compensate for the higher noise such voltage levels would produce at low currents.

Figure 5 is a schematic representation of a specific embodiment of a RTD transducer **200** within the scope of the invention. In general terms, this embodiment can be envisioned as a conventional magnetoresistive (MR) or giant magnetoresistive (GMR) transducer in which the MR element used to read data has been replaced by a stripe **210** of RTD material. However, the design of conventional MR and GMR read elements are heavily constrained by the need for permanent magnets **222**, bias fields, and appropriately designed current leads **220**, **221** in close proximity to the actual field sensing material **210**. Thus, the transducer of Figure 5 may be appropriate in some circumstances because it presumably could be manufactured relatively easily by using only a simple modification of a manufacturing process that is currently used in high volumes. However, the transducer of Figure 5 would not be possible in many circumstances because it includes features that are not required once the constraint of a MR or GMR element is removed.

In each of the embodiments described above, an optional additional feature includes actively heating the transducer element to place it within an optimal operating temperature range. In non-heated embodiments, some Joule heating of the biased temperature sensitive resistor itself will heat the transducer by an amount that may be significant depending on the parameters and materials chosen. But it may be desirable to generate additional heat to achieve a larger temperature differential between the transducer and the patterned medium surface. As illustrated schematically in Figure 6, one technique for actively heating the transducer element is to add a heating element **230** in close proximity to the temperature sensitive resistor **210**. Heating element **230** adds additional complexity to the transducer construction, but would still involve relatively simple

materials to implement. Energy would be provided to heating element **230** in a conventional manner (not shown for clarity) that is not critical to the scope of the invention.

As illustrated schematically in Figure 7, an optional additional feature includes a protective coating layer **240** on the bottom of transducer **200**. This mechanically robust feature also provides high thermal conductivity between the patterned medium and the resistor element **210**. A suitable material for coating layer **240** is diamond-like carbon (DLC) but the invention is not limited to this material. Also, coating layer **240** may be added to any of the embodiments of the invention described above.

In each of the embodiments described above, references to particular elements (*e.g.*, nickel and platinum) should be understood to include not only pure elements but also alloys that include such elements, according to principles known in the art of electromagnetic structures.